UNDERSTANDING NEUTRINO PROPERTIES USING ASTROPHYSICAL FLUXES

Imperial College Seminar

Jack Franklin

IPPP, Durham University

16/10/2024

JUNO AS A PROBE OF THE PSEUDO-DIRAC NATURE USING SOLAR NEUTRINOS

JF, Yuber F. Perez Gonzalez, Jessica Turner PhysRevD.108.035010

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- But we can also add a *Majorana* mass term

$$\mathcal{L}_\nu \supset -Y_{\alpha i} \bar{L}_\alpha \tilde{H} N_R^i + \frac{1}{2} \left(N_R^i\right)^c M_R^{ij} N_R^j + h.c.$$

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- Which looks a bit nicer if we write it in matrix form:

NEUTRINO MASS MECHANISM

$$\mathcal{L}_\nu \supset -\frac{1}{2}\bar{\Psi}^c M \Psi$$

with $\Psi = \begin{pmatrix} \nu_L \\ N_R^c \end{pmatrix}$ and $M = \begin{pmatrix} 0_3 & \frac{Y^T v}{\sqrt{2}} \\ \frac{Y v}{\sqrt{2}} & M_R \end{pmatrix}$

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    - UV theories (e.g. Majoron theory)

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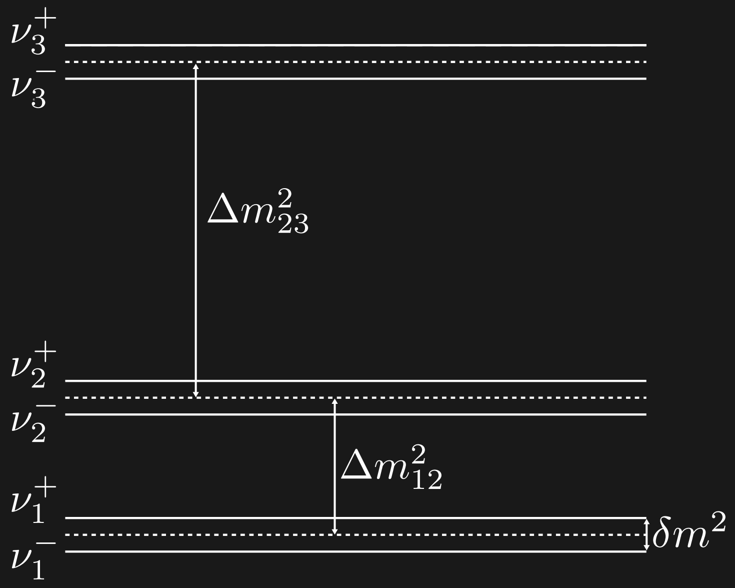

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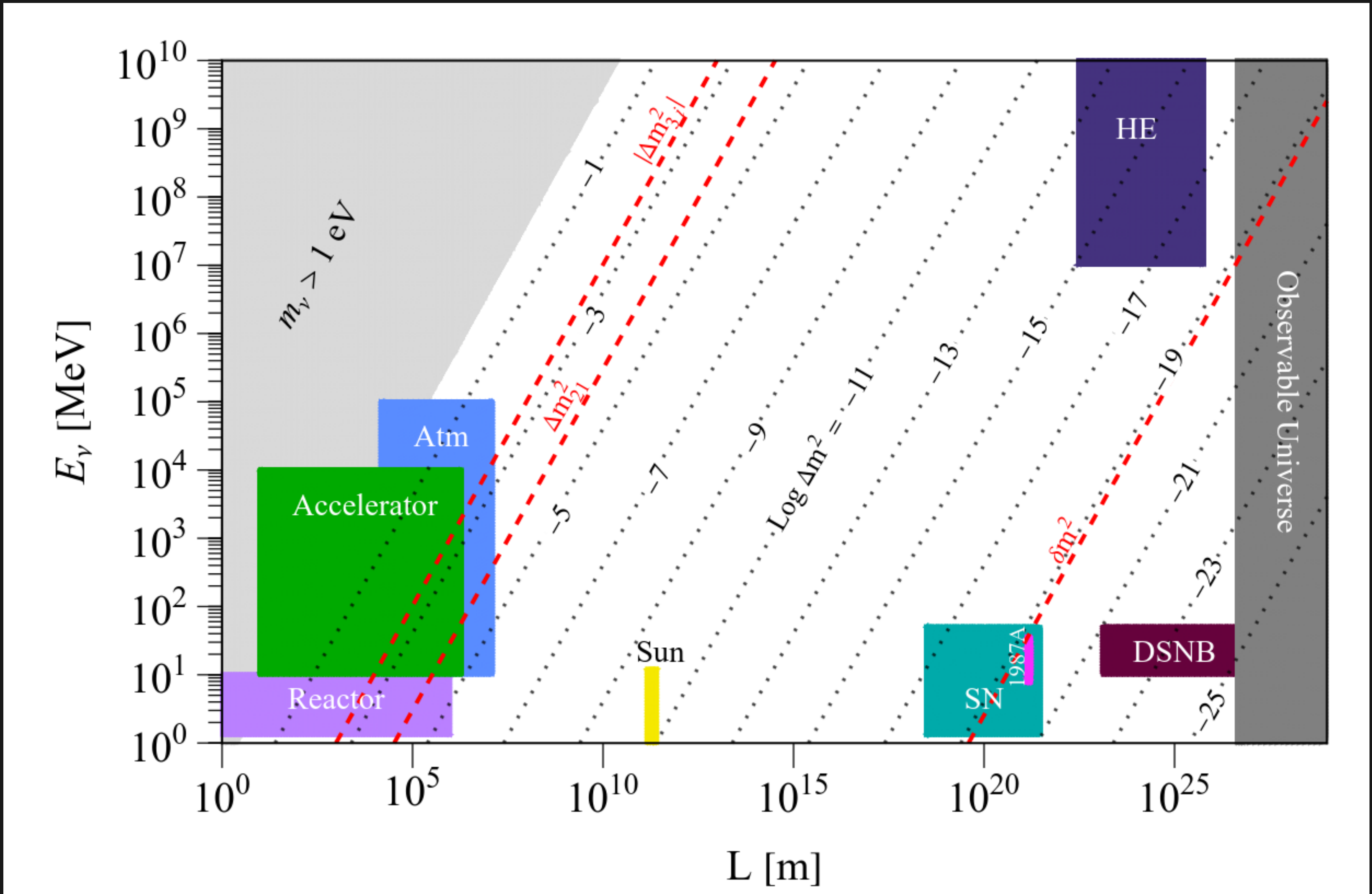

Source: doi:10.1103/PhysRevD.105.095019

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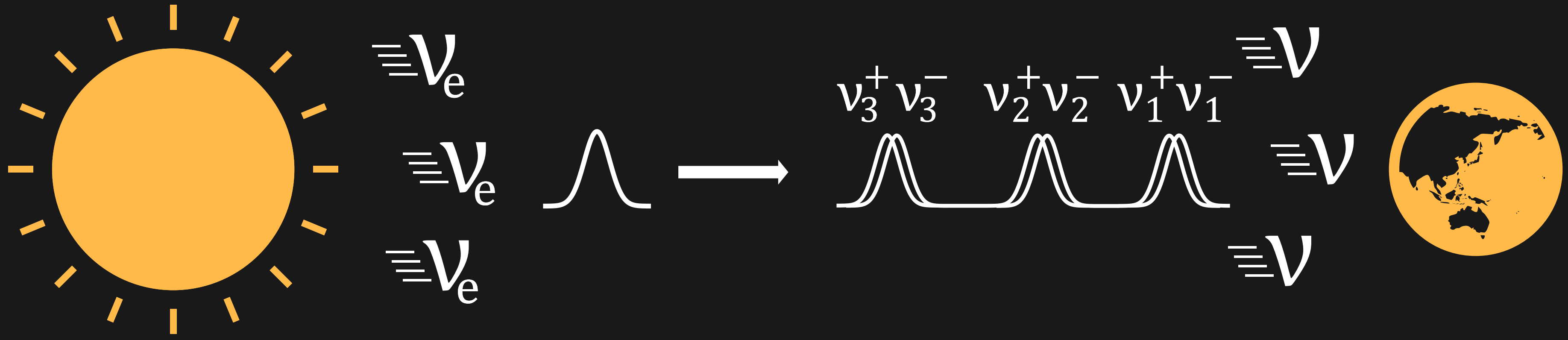
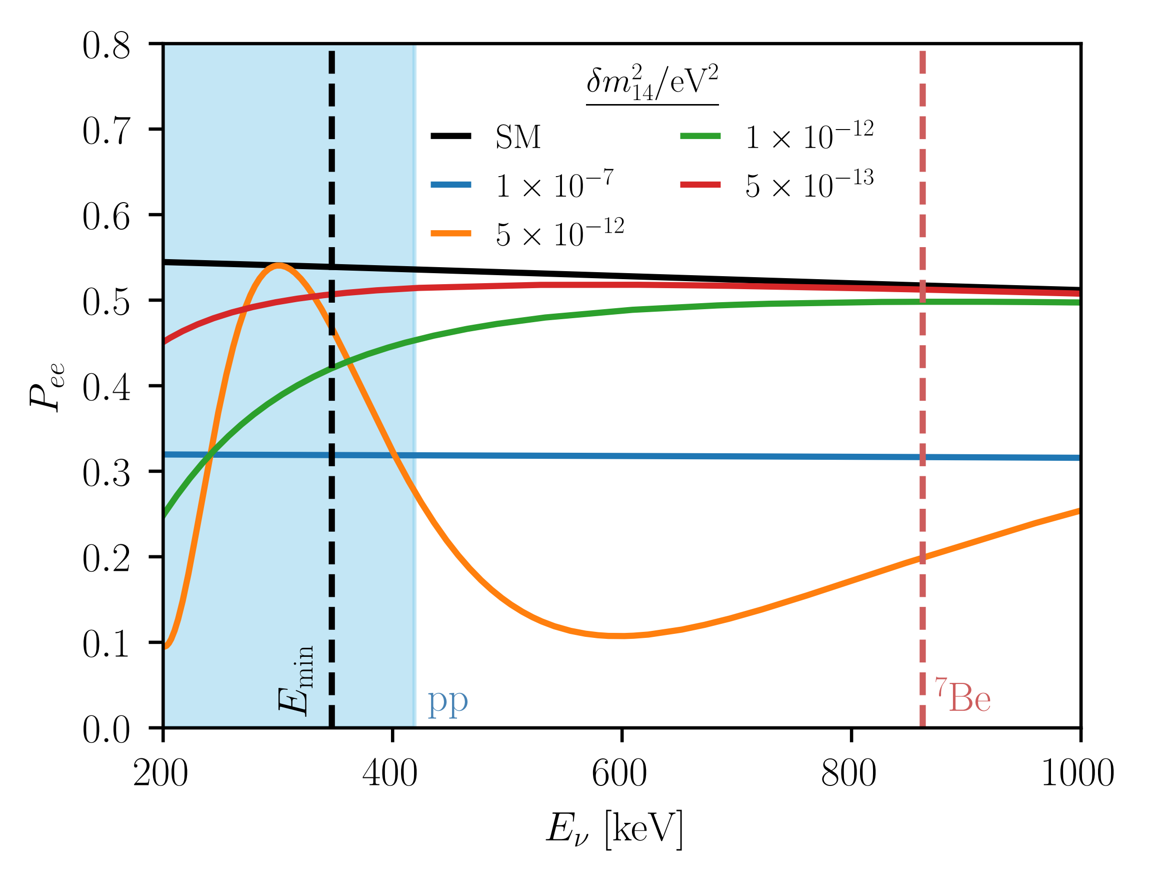


TESTING FOR THE PSEUDO-DIRAC SCENARIO



SOLAR NEUTRINOS AT JUNO

Credit: Xinhua / Alamy Stock Photo

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- The Jiangmen Underground Neutrino Observatory (JUNO) Experiment:

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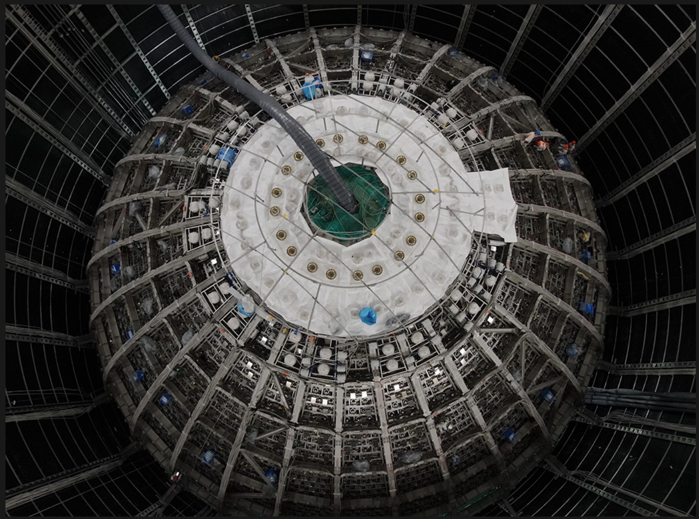

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SOLAR NEUTRINOS AT JUNO

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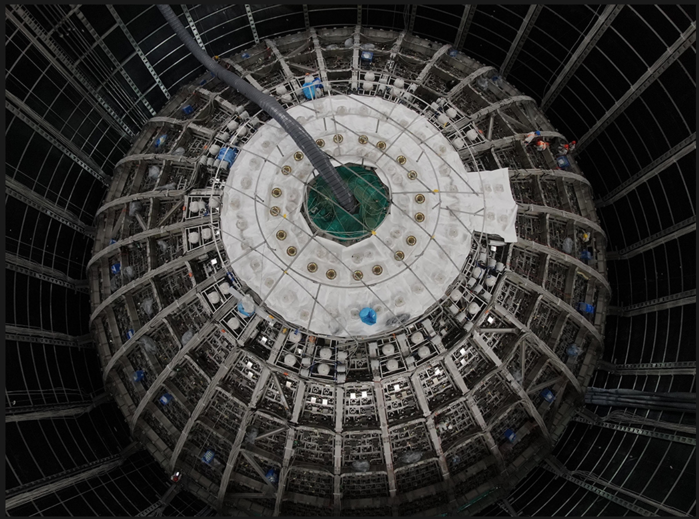

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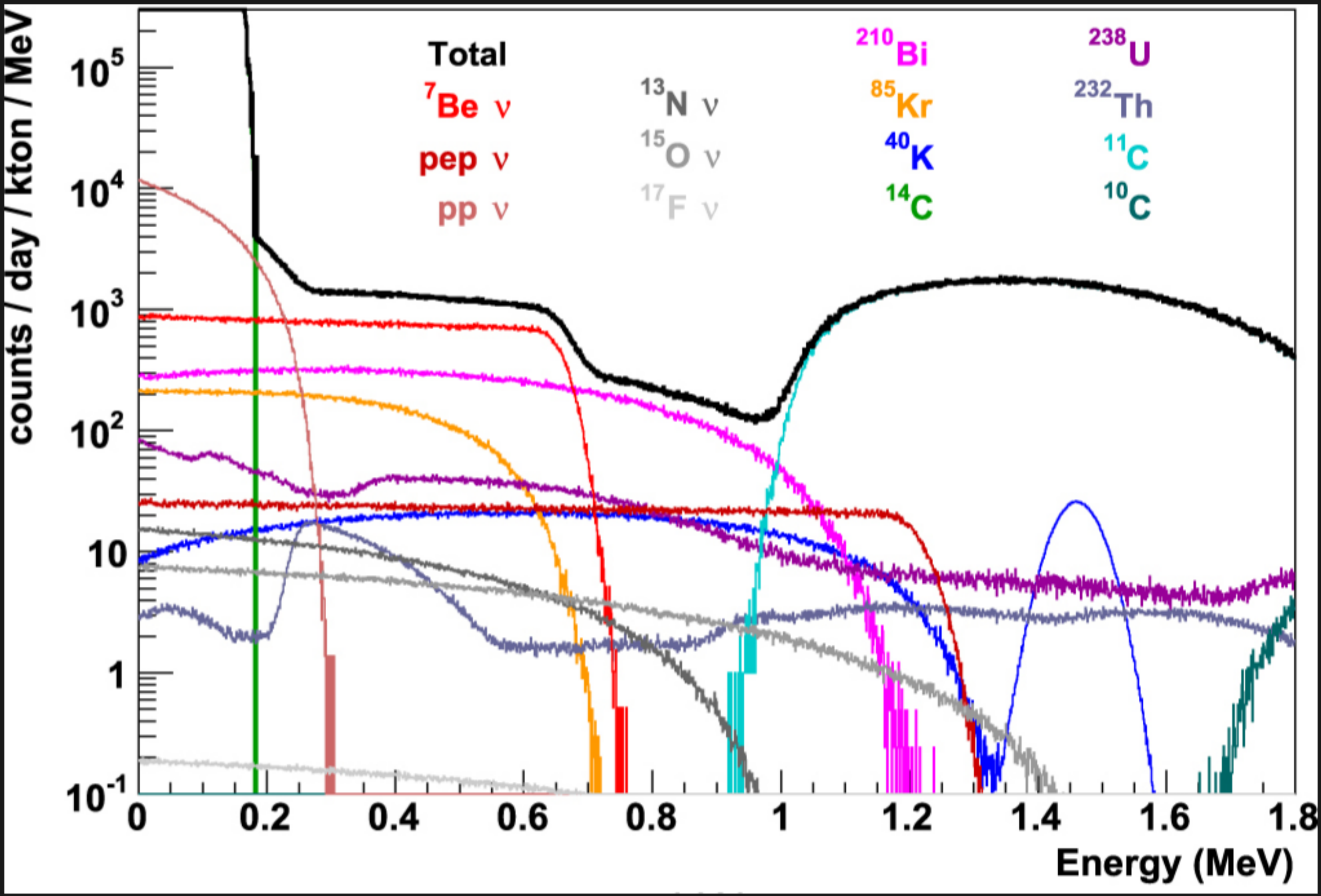
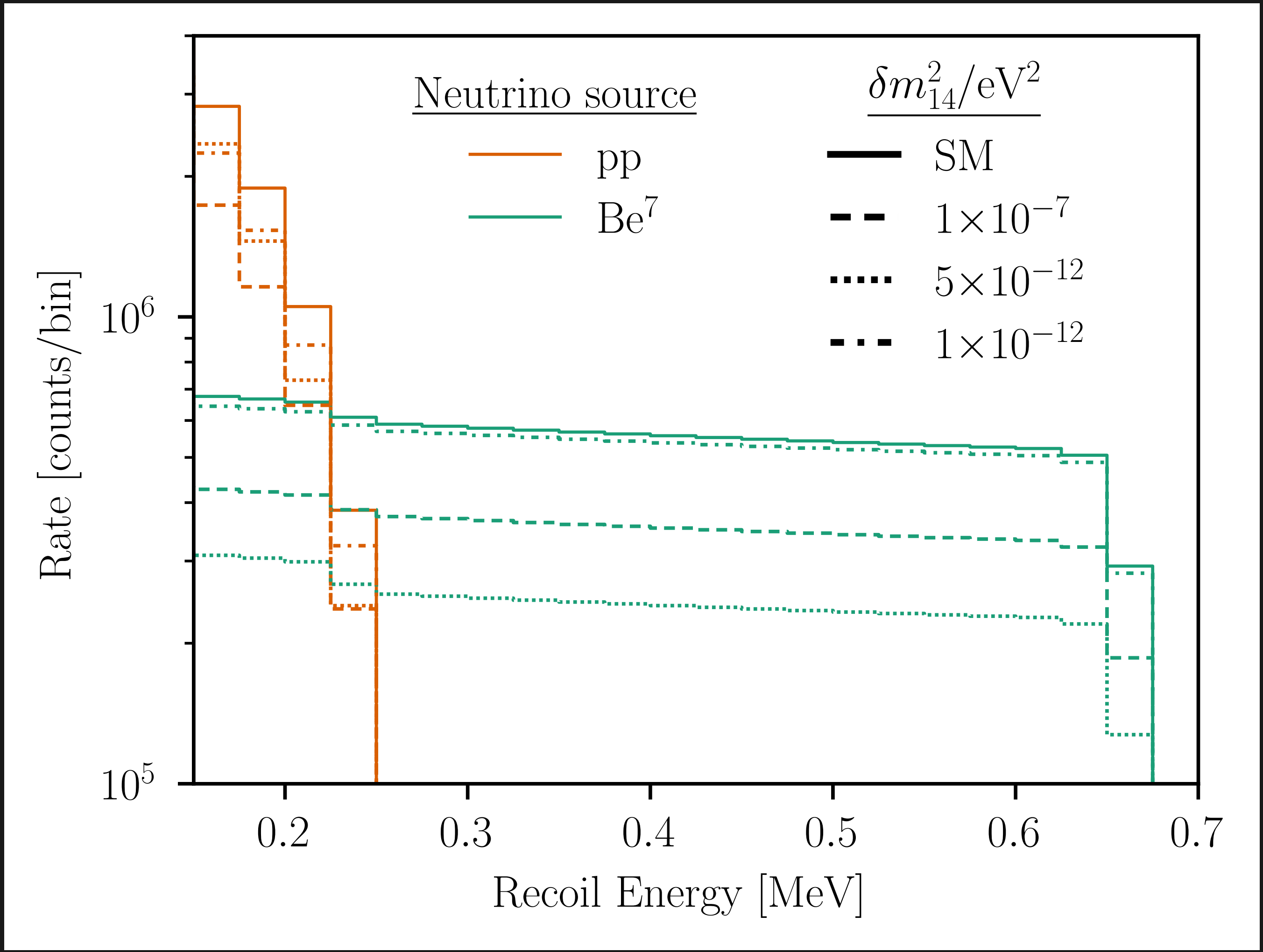


Modelled Backgrounds at JUNO. Credit: JUNO Collaboration

ANALYSIS

Compare to events expected from solar flux models:



Events at JUNO

ANALYSIS

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- Chi-squared analysis:

$$\chi^2 = \sum_i \frac{(\sum_a \alpha_a N^{i,a}_{\mathrm{BSM}} + \sum_b (\alpha_b - 1) N^{i,b} - N^i_{\mathrm{SM}})^2}{N^i_{\mathrm{SM}} + \sum_b N^i_b}$$

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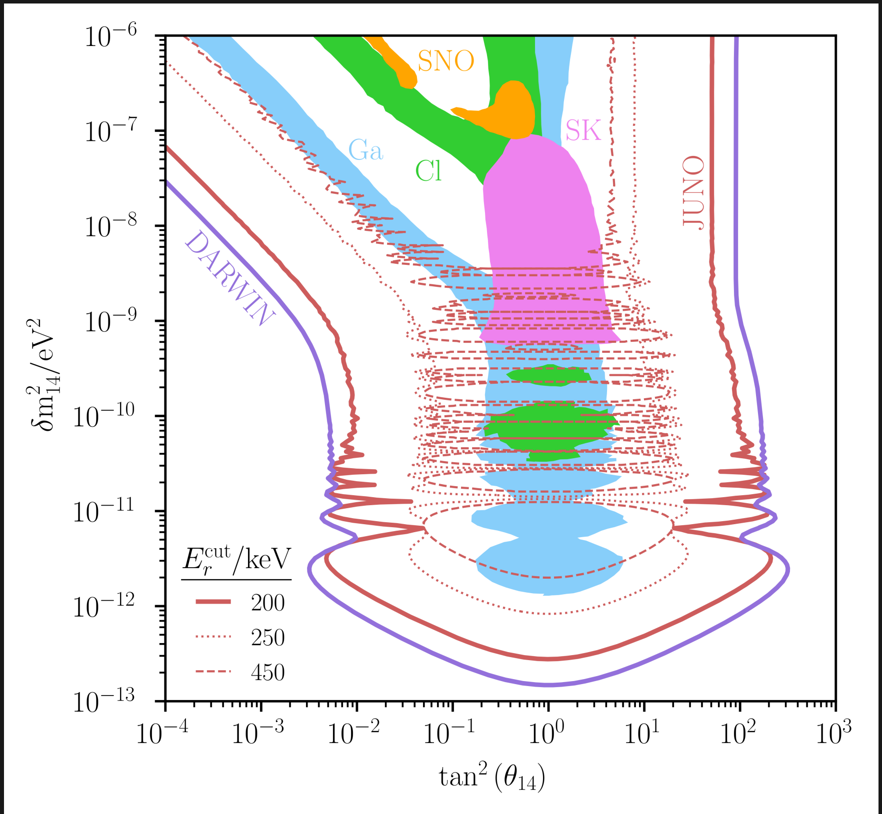
RESULTS

SCENARIO 1:

Single mass splitting, δm^2_{14}



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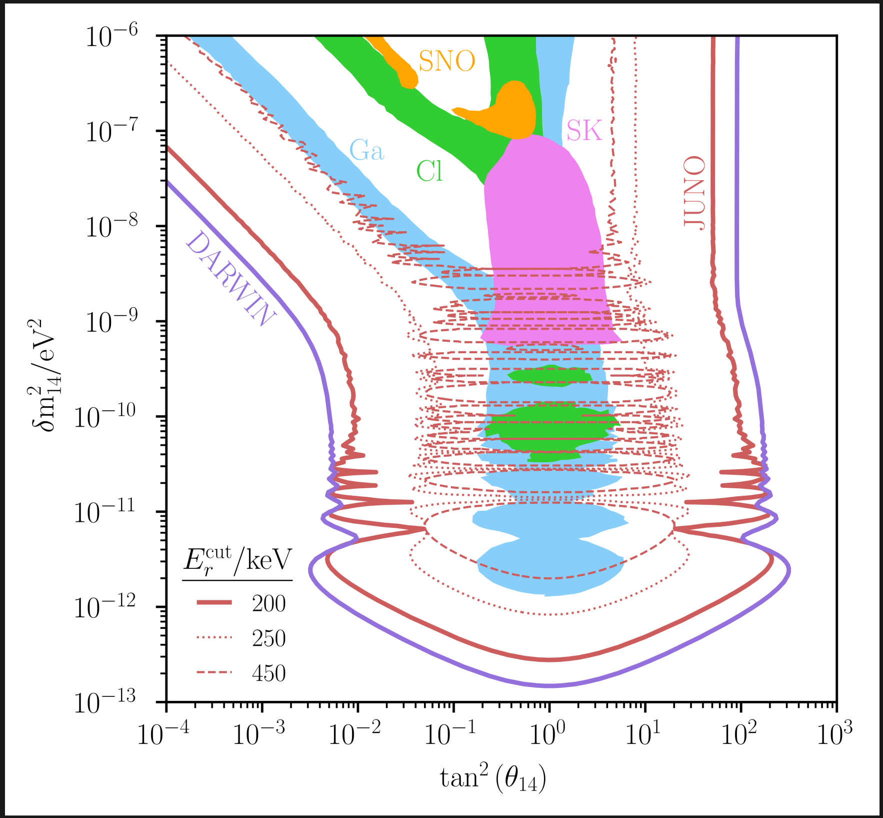

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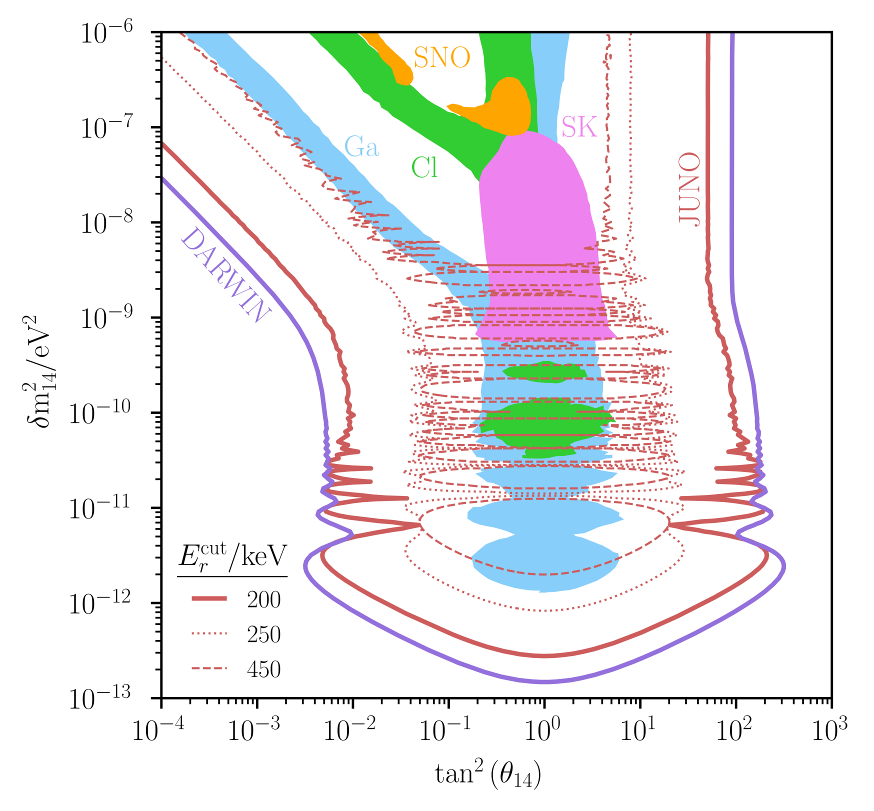

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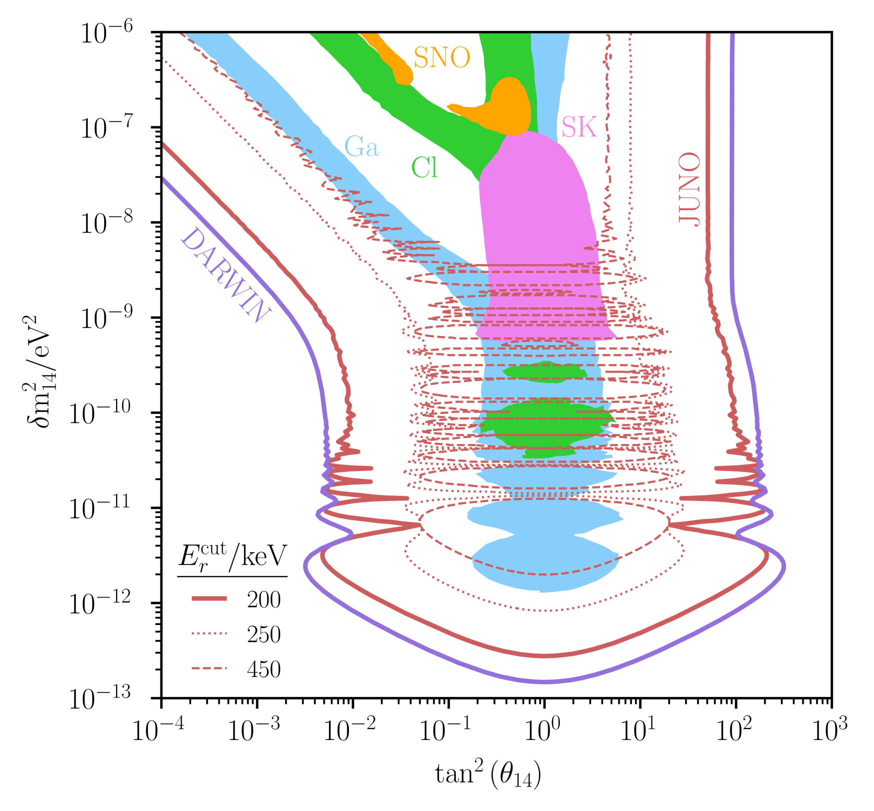

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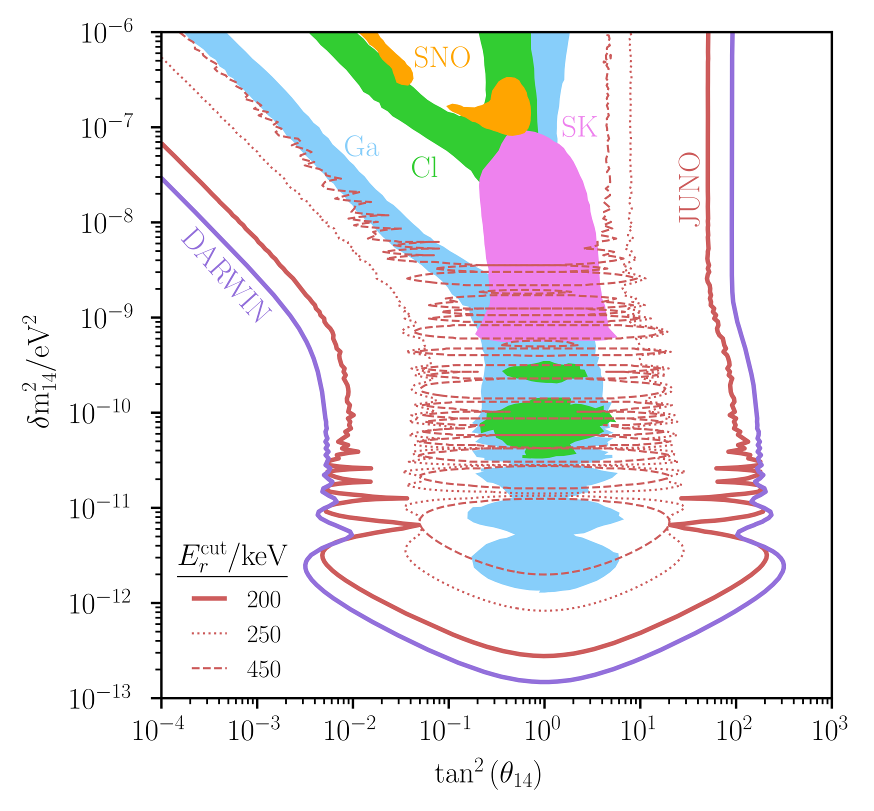

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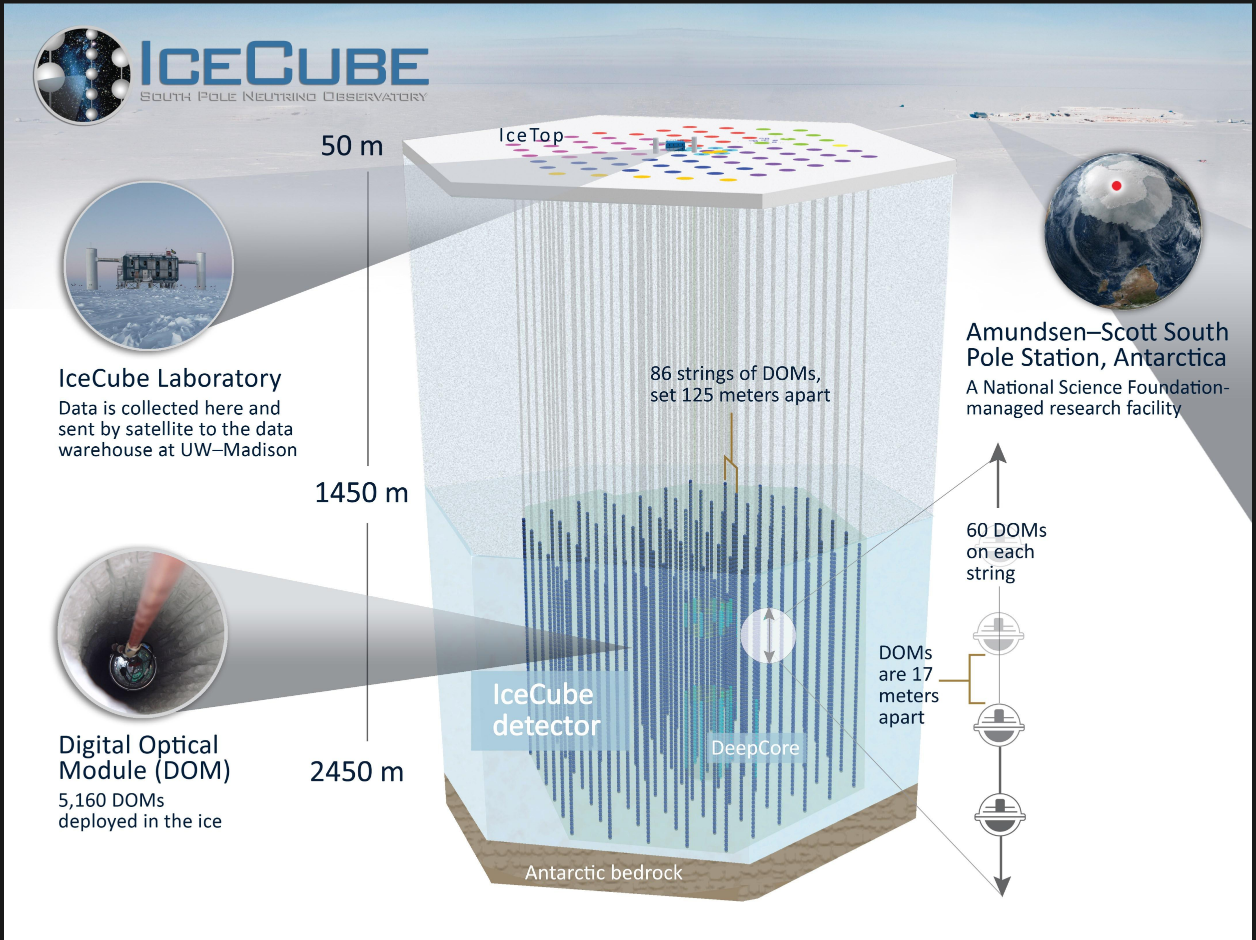
- Potential improvement of over an order of magnitude!

CONSTRAINS ON SECRET INTERACTIONS FROM POINT SOURCES AT ICECUBE

JF, Ivan Martinez-Soler, Yuber F. Perez Gonzalez, Jessica Turner

ICECUBE



IceCube Experiment. Credit: IceCube Collab.

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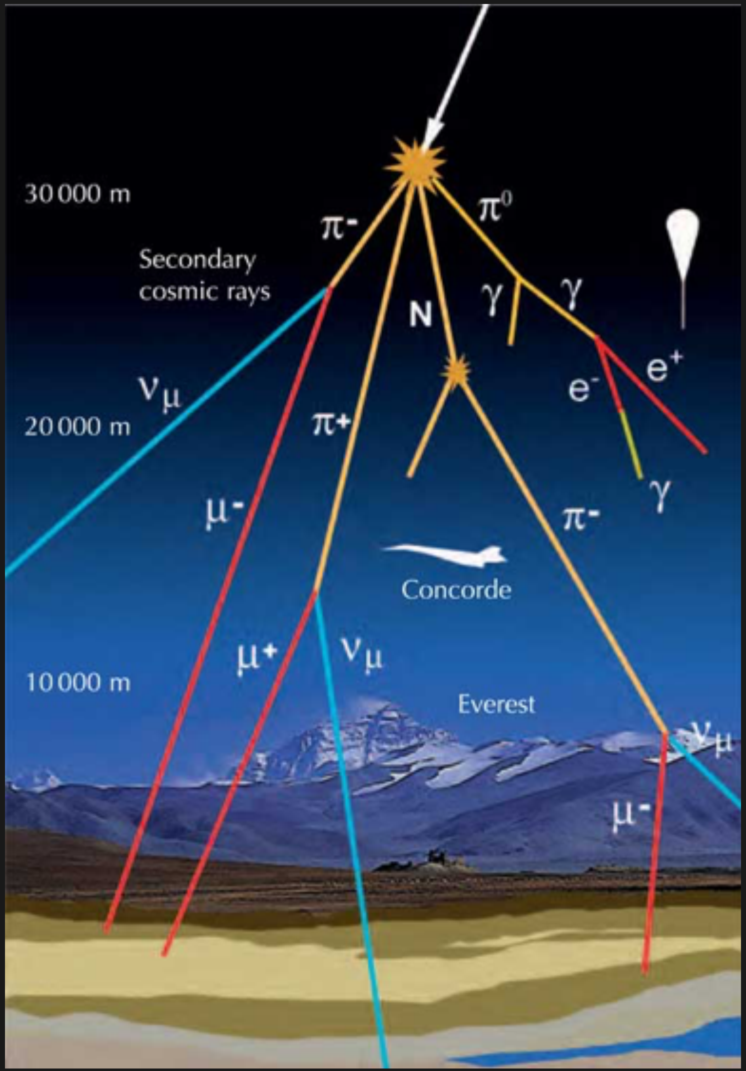

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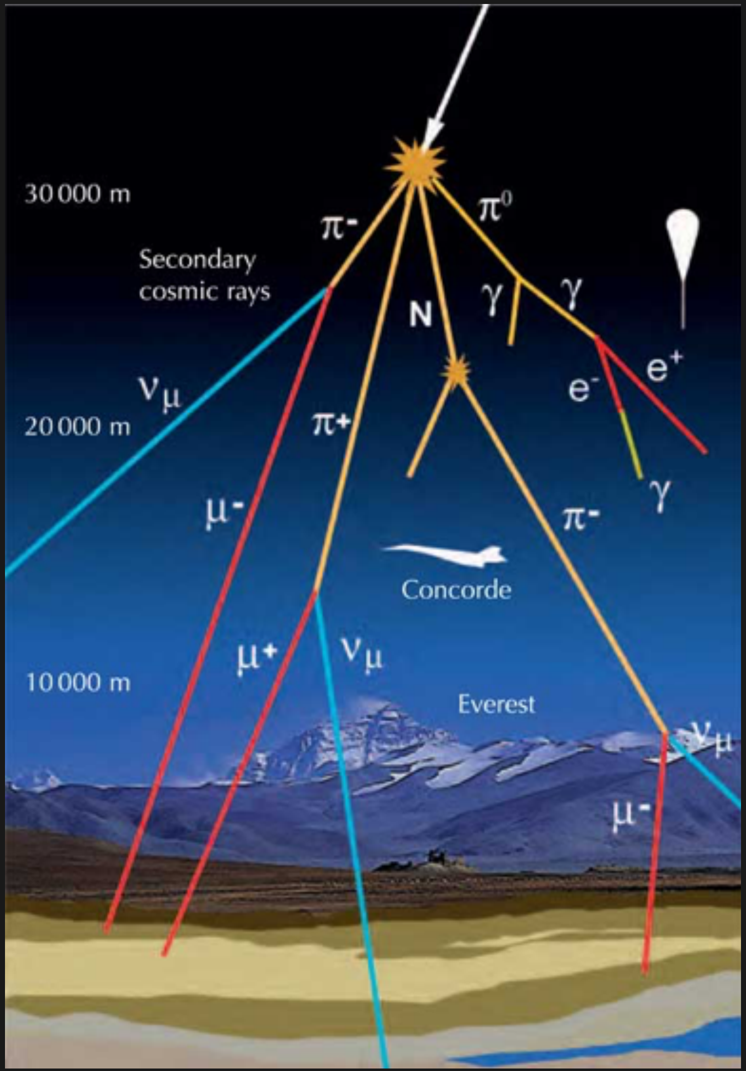

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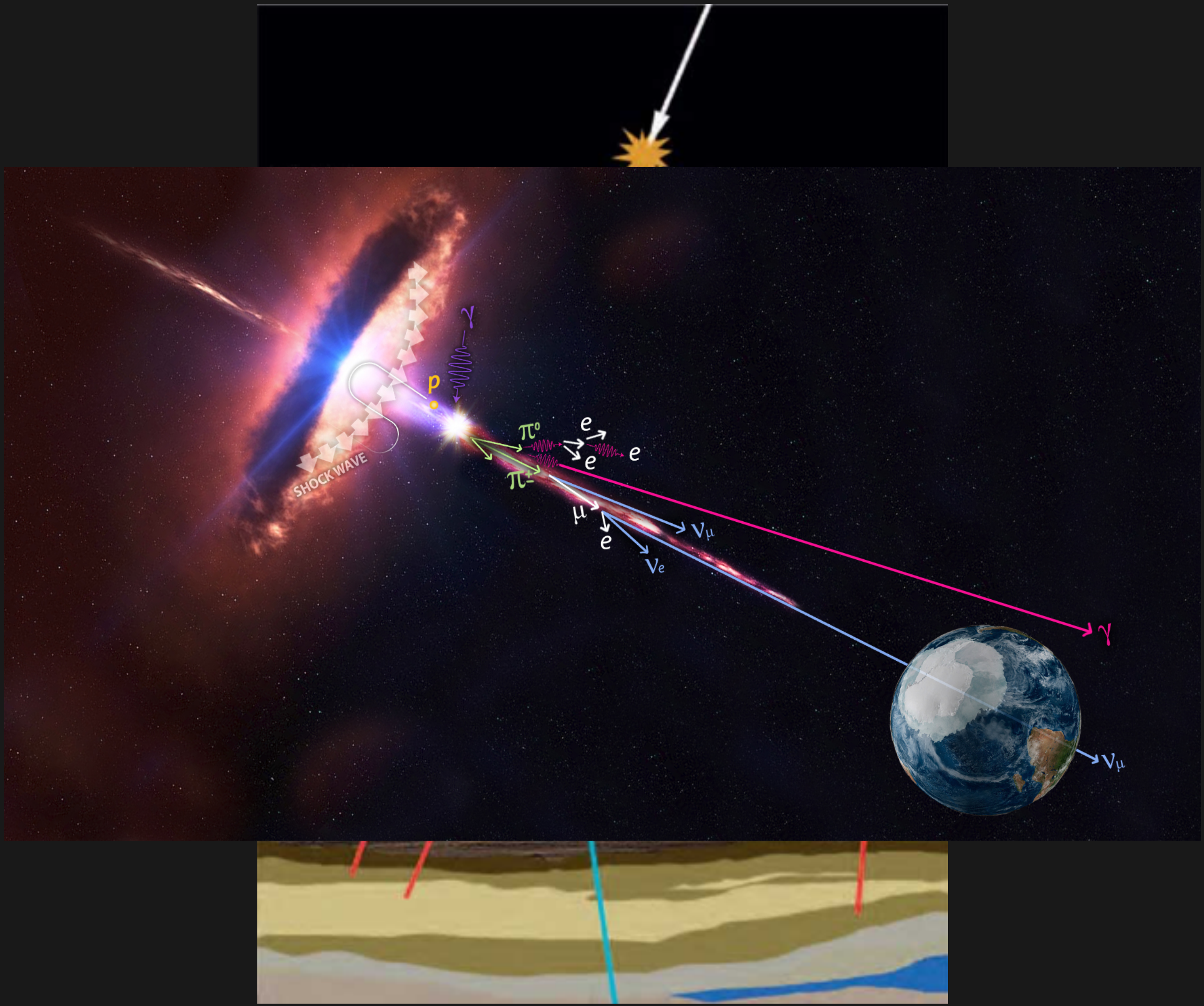

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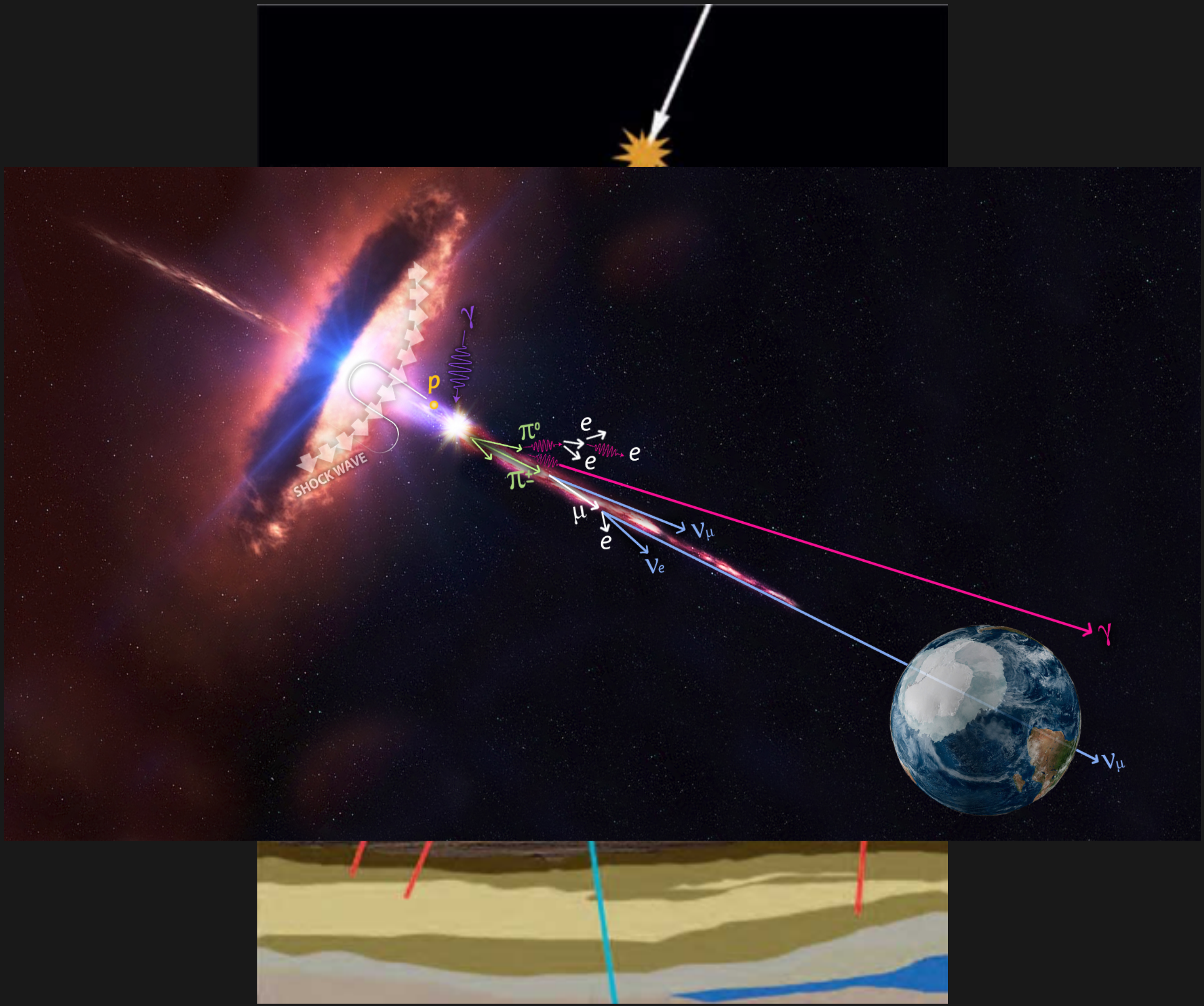

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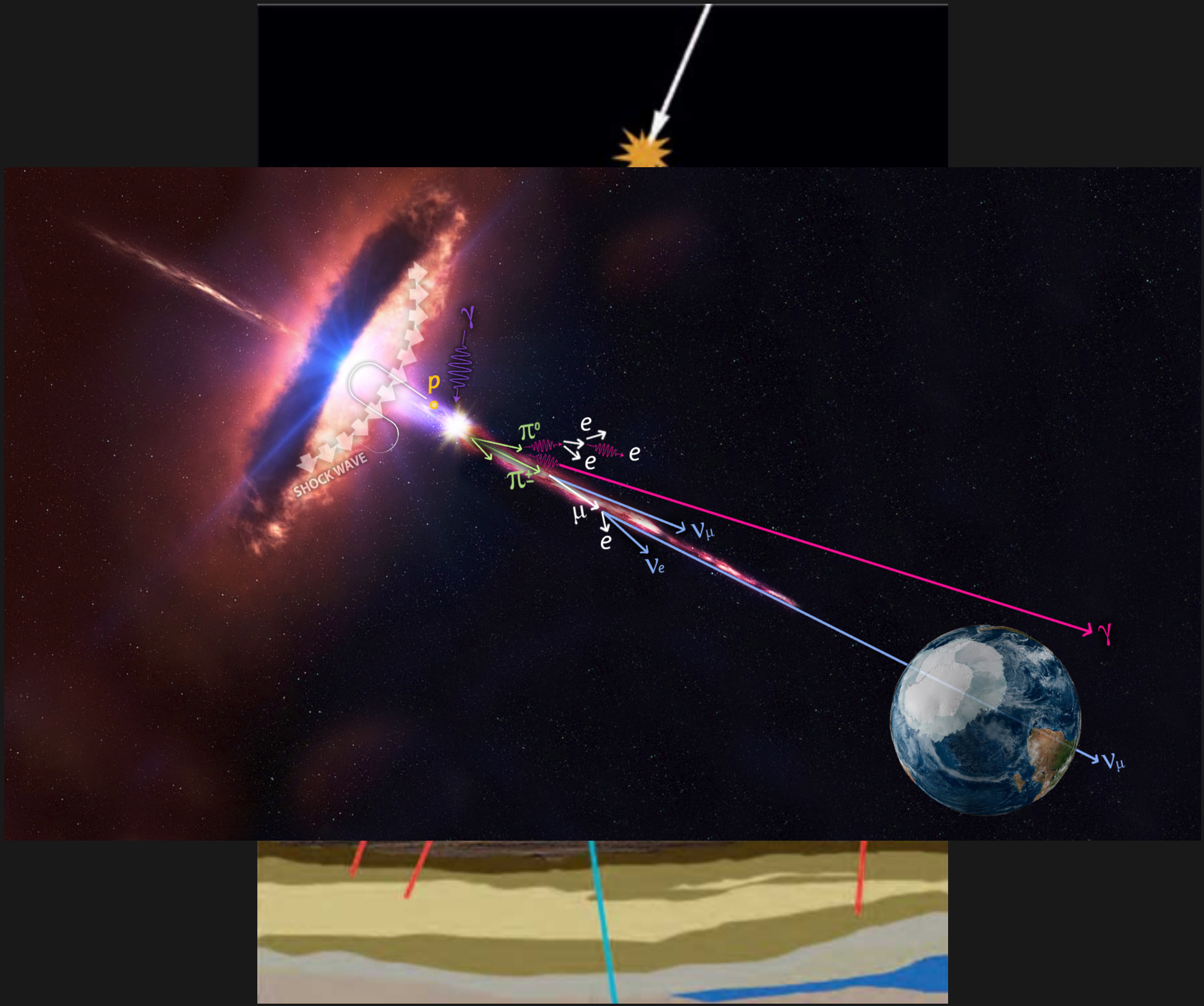

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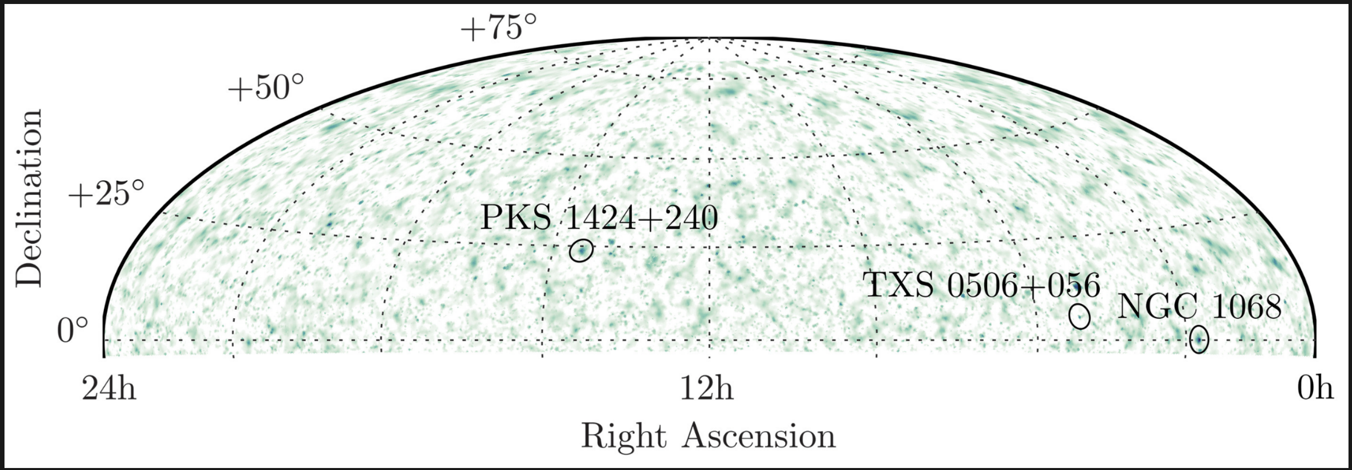

Credit: IceCube Collab.

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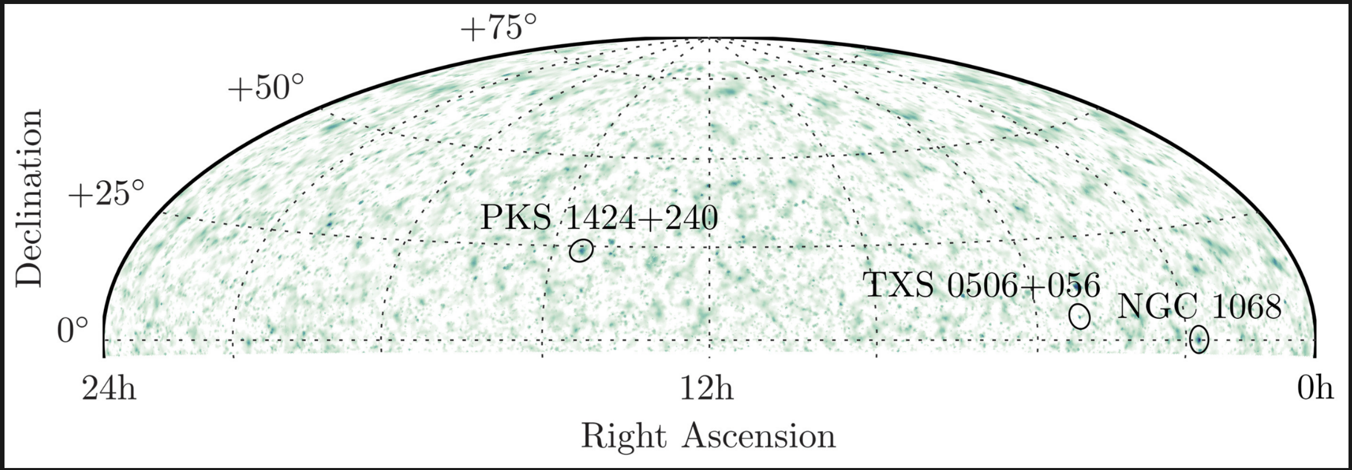

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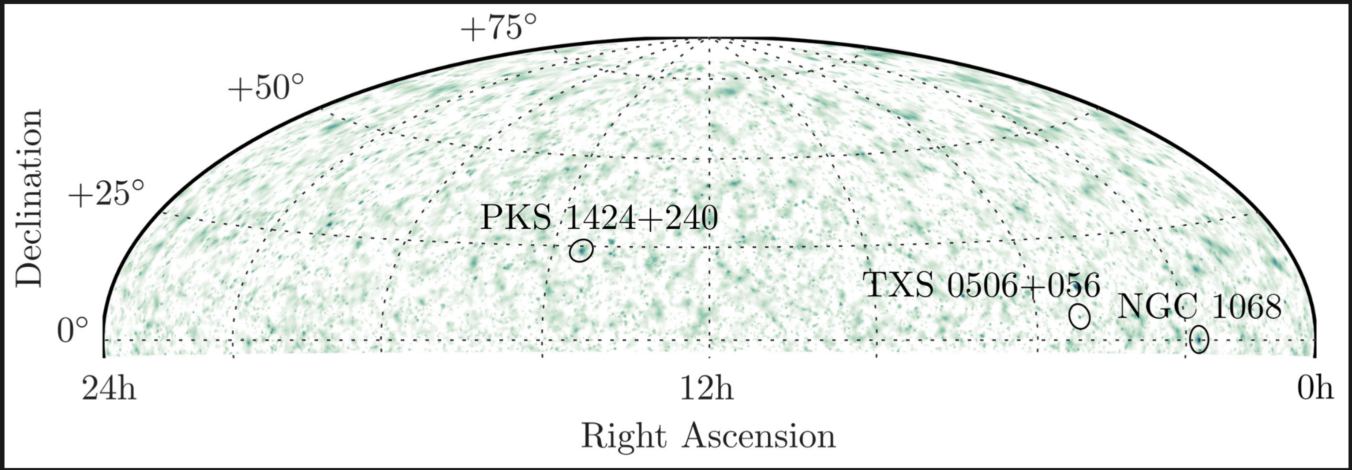

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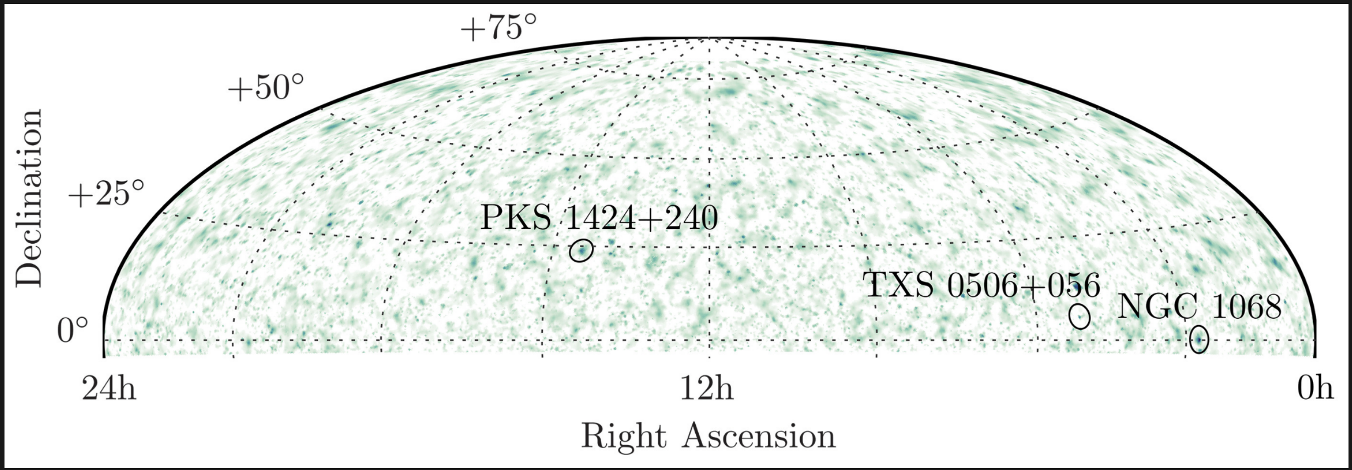

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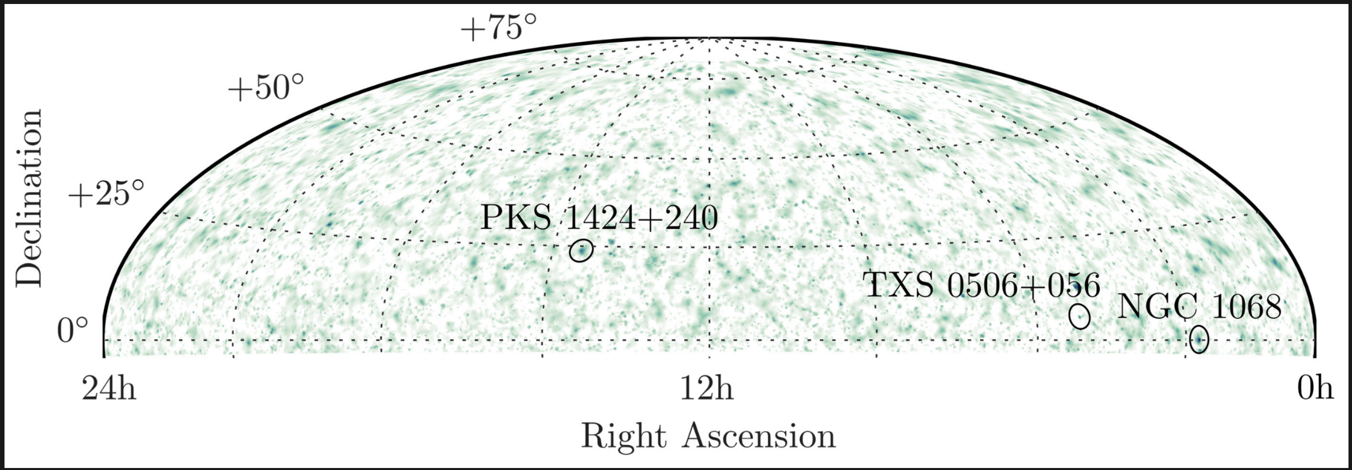

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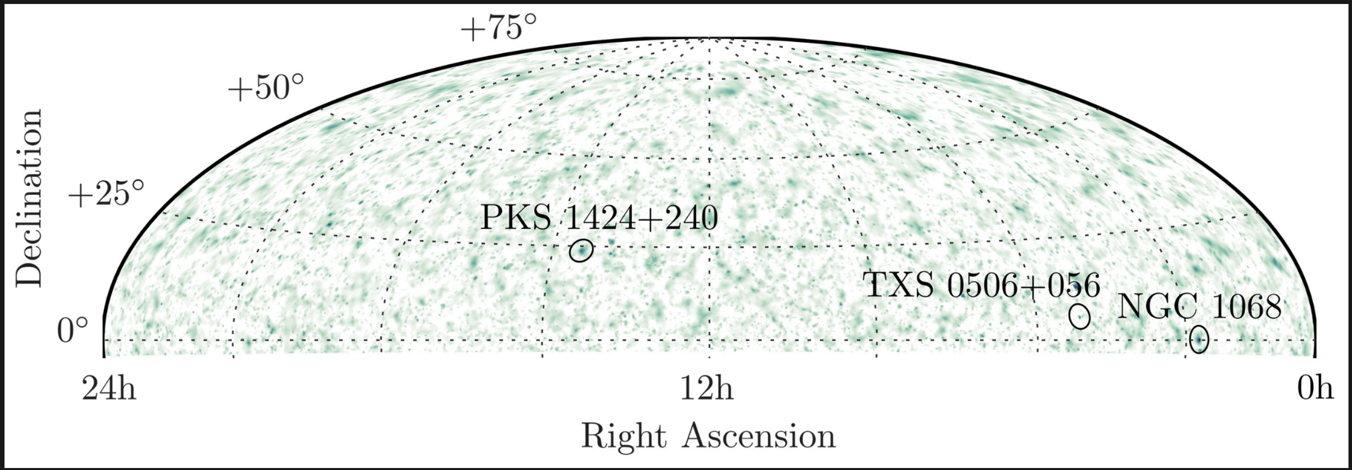

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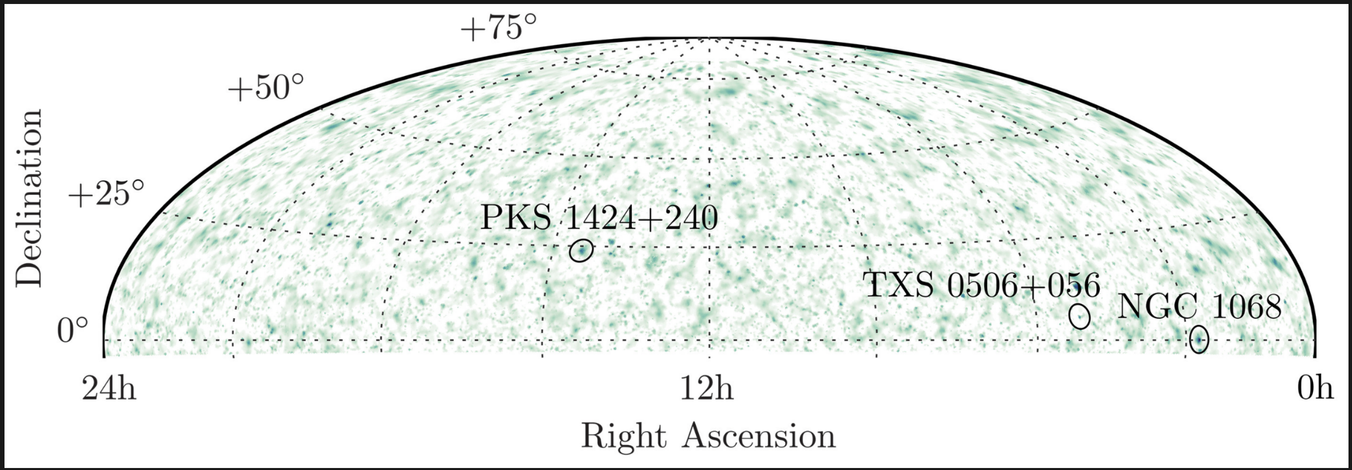

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Identify with unbinned log-likelihood ratio test:

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- $\vec{\theta}$: Source flux parameters

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- Test-statistic:

$$TS(\vec{d}_{\mathrm{src}}) = -2\log\left(\frac{\mathcal{L}(n_s = 0|\{\vec{x}_i\})}{\sup_{n_s,\gamma}\mathcal{L}(n_s,\gamma,\vec{d}_{\mathrm{src}}|\{\vec{x}_i\})}\right)$$

POINT SOURCES AT ICECUBE

Values from SkyLLH Analysis

Source	$\hat{n}_s$	γ	**TS**	$-\log_{10}(p)$
NGC 1068	56	3.15	19.56	4.25(5.04σ)
PKS 1424+024	49	3.86	13.29	2.89(4.03σ)
TXS 0506+056	15	2.17	13.18	2.86(4.01σ)

NEUTRINO SECRET INTERACTIONS

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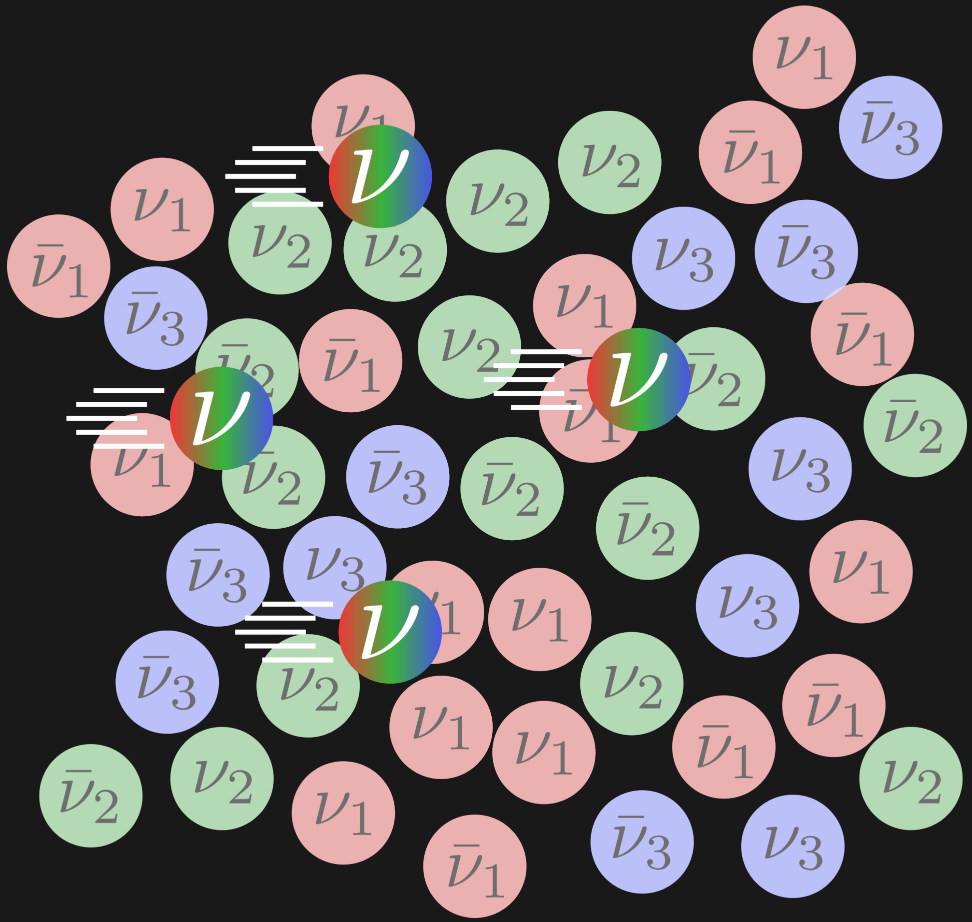

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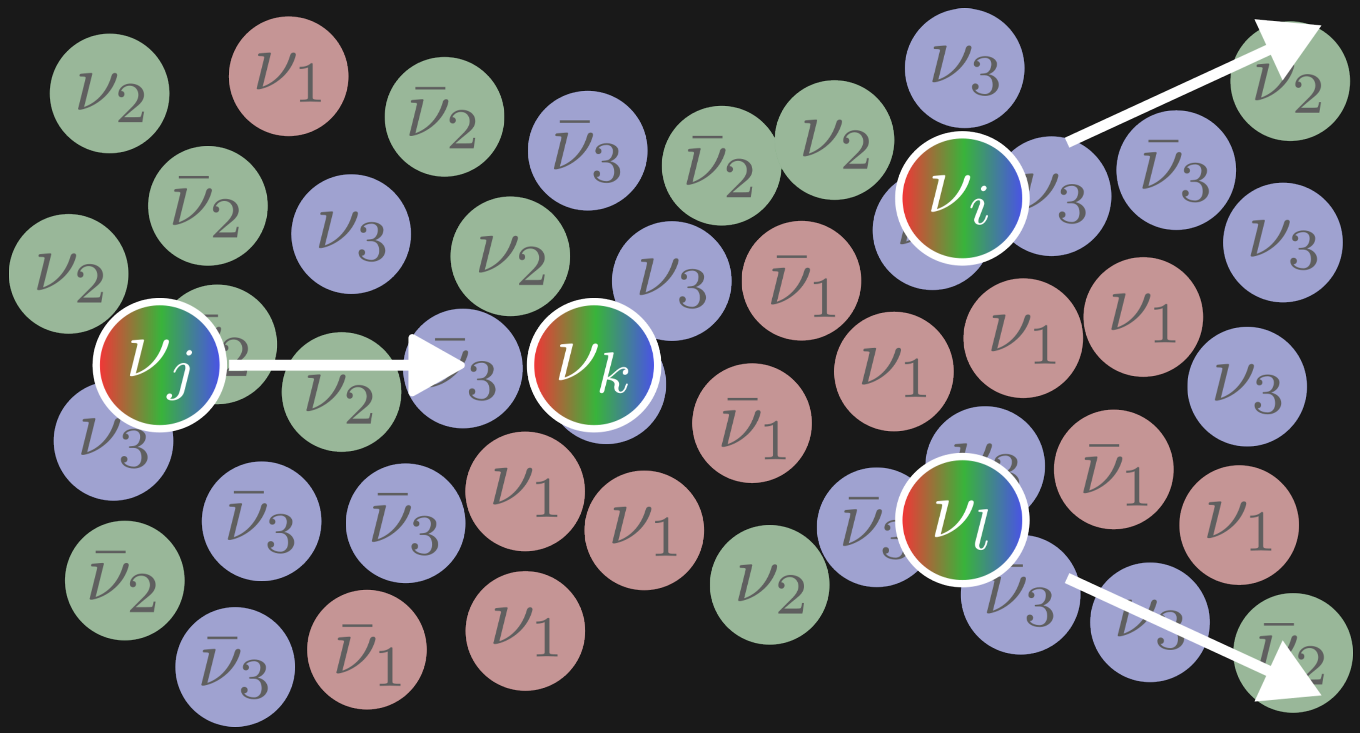

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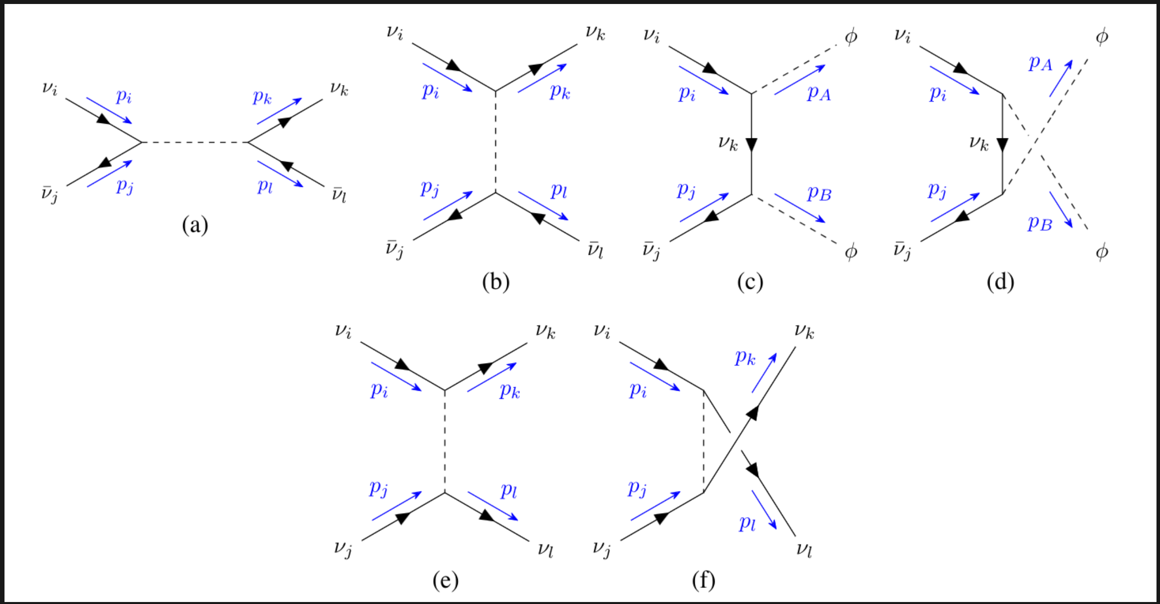

Relevant Feynman Diagrams. Source: PhysRevD.104.123014

FINDING THE FLUX

$$\frac{d\phi(t, E_\nu)}{dt} = \frac{\partial}{\partial E_\nu}\left[H(t) E_\nu \phi(t, E_\nu)\right]$$

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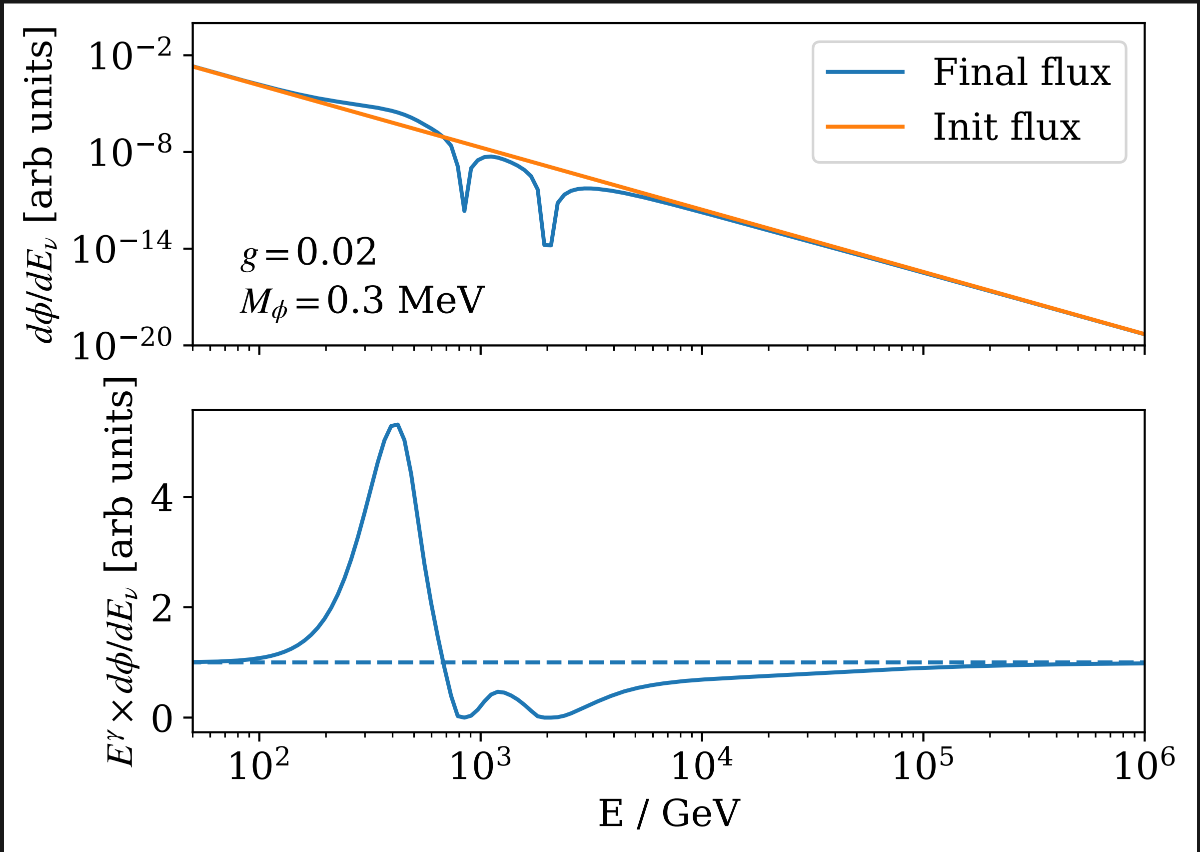

Effect of SI on flux from TXS

ANALYSIS

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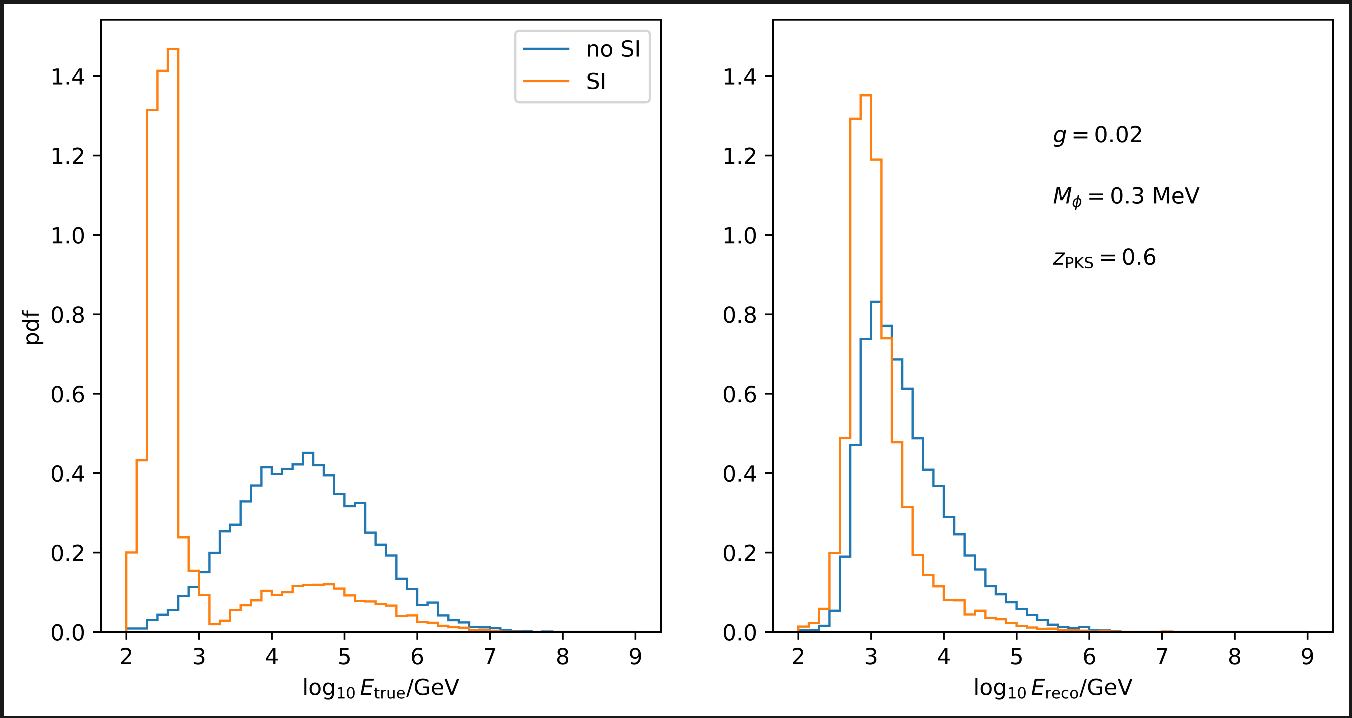

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- Use power-law point source as null hypothesis:

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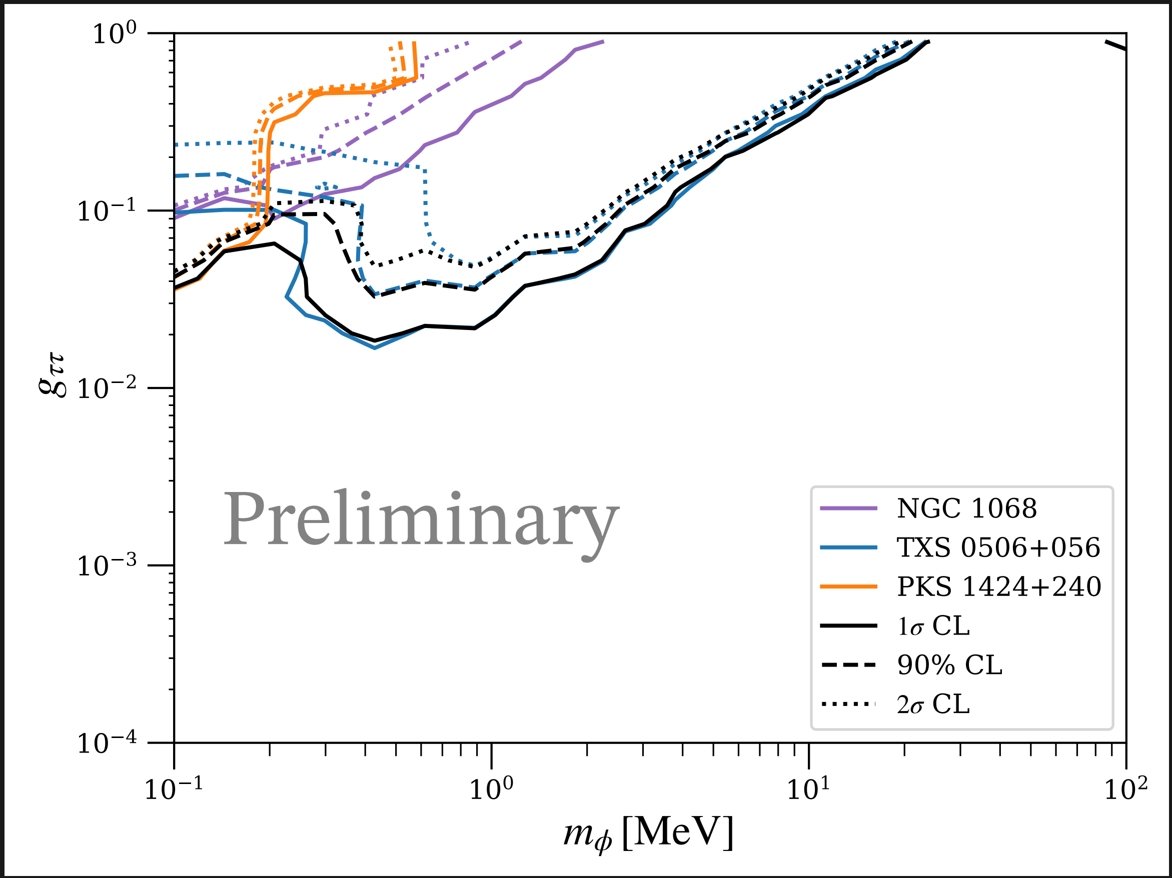
- Maximise TS to fit the new flux to data

RESULTS



10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$g_{\tau\tau}$
10^{-1}
10^0
10^1
10^2
m_ϕ [MeV]
Preliminary
NGC 1068
TXS 0506+056
PKS 1424+240
1σ CL
90% CL
2σ CL

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- This allows us to probe fundamental questions about the nature of neutrinos
- As statistics grow over time, the power of these analyses will only improve
- Future experiments (e.g. JUNO, IceCube Gen2) will improve our knowledge by orders of magnitude!

BACKUP SLIDES

EVENTS